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Distribution of Forage of Skipjack Tuna (*Euthynnus pelamis*) in the Eastern Tropical Pacific

MAURICE BLACKBURN and R. MICHAEL LAURS

SEATTLE, WA.
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Distribution of Forage of Skipjack Tuna *(Euthynnus pelamis)* in the Eastern Tropical Pacific[1]

By

MAURICE BLACKBURN[2] and R. MICHAEL LAURS[3]

ABSTRACT

The fishery for skipjack tuna (*Euthynnus pelamis*) in the eastern Pacific Ocean might be extended if offshore areas of high skipjack abundance were known. One would expect the numbers of skipjack in these offshore areas to be related to the distribution of known skipjack forage organisms in the micronekton. The EASTROPAC oceanographic cruises yielded net-caught micronekton samples over large parts of the eastern tropical Pacific during seven successive 2-month periods. From these samples, the occurrence of organisms known to be prey of skipjack was expressed as ml/1000 m^3. Charts of night and day concentrations in the upper 200 m were produced for each of the seven periods.

In the region from long 92° to 119° W the major areas of maximum concentration of potential skipjack forage remained essentially constant during most periods. Two of these areas lie parallel to the equatorial upwelling zone—one just to the north, the other just to the south. Another zonal area of abundant forage generally occurs between lat 6° and 14° N. Forage is also frequently abundant between lat 14° and 20° N and long 107° and 119° W.

The concentrations of skipjack forage in these areas are comparable with those in nearshore parts of the eastern tropical Pacific, where the present skipjack fishery occurs. The abundance of skipjack in the forage-rich offshore areas might therefore be sufficient to support commercial fishing operations. Sea-surface temperatures are generally suitable for skipjack in those areas. On three recent crossings of the equatorial region at about long 119° W, skipjack appeared to be abundant in the first three areas of high forage concentration mentioned above.

INTRODUCTION

Most of the fishery for skipjack tuna (*Euthynnus pelamis*) in the eastern tropical Pacific lies within a few hundred miles of the American coast. Skipjack taken in these waters probably represent adolescent stages of a migratory population which breeds in the central tropical Pacific, and is not being fully exploited (Rothschild, 1965; Joseph and Calkins, 1969). The United States tuna fishery in the eastern tropical Pacific may become increasingly dependent upon skipjack. The tropical Pacific tuna fleet continues to grow in size in spite of the fact that the fishery for yellowfin tuna (*Thunnus albacares*) is regulated, and other than skipjack there is no equally available and

[1]This work was supported by the National Marine Fisheries Service (former Bureau of Commercial Fisheries), both directly and through Contracts 14-17-0007-458, 14-17-0007-742, 14-17-0007-963, and 14-17-0007-2311 with the Institute of Marine Resources, University of California. It was part of the research of the Scripps Tuna Oceanography Research Program of the Institute of Marine Resources.

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commercially marketable species. However, the fishery for skipjack has not been able to extract more than 265 million pounds (120,-200 metric tons) from the coastal areas and the neighboring islands in any year in the period since the yellowfin fishery was first regulated in 1966, and the yearly catch from those areas has been as low as 127 million pounds (57,600 metric tons) (Inter-American Tropical Tuna Commission, 1970).

Thus, new fishing grounds for skipjack are needed. Attention has been focused on the possibility of extending the fishery from the coastal areas, where present effort is mostly confined, out into the offshore areas to the west, where the abundance of skipjack is unknown. Because of their proximity to the spawning grounds, some of these offshore areas may yield larger fish than are taken near shore, and the larger fish are better suited for canning. Miyake (1968) showed that skipjack, including some of large size, occur throughout the tropical Pacific. It would aid the U.S. tuna fleet to know where in the unfished offshore regions of the eastern tropical Pacific skipjack are most abundant, and which areas offer the most potential as a commercial skipjack fishery.

A first step in determining the distribution of these offshore skipjack was to identify areas where environmental conditions are most suitable for them. The cooperative EASTROPAC oceanographic expedition of 1967-1968, which was coordinated by the National Marine Fisheries Service (former Bureau of Commercial Fisheries), was designed to accomplish this and other objectives.

Previous investigations indicate that adult tunas aggregate where food is abundant in waters that are within certain ranges of temperature, which vary from species to species (Blackburn, 1965). Specifically, this has been confirmed for skipjack and yellowfin tuna in the fishery area off Baja California in the eastern Pacific (Blackburn, 1969). In the eastern Pacific fishery region, most skipjack aggregations occur in water between approximately 20 and 29 C (Williams, 1970). Skipjack are fished by U.S. fishermen at or near the sea surface, so surface temperatures are sufficient to identify areas where temperature is suitable. Charts of mean monthly surface temperature show that most parts of the eastern tropical Pacific have temperatures suitable for skipjack nearly all the year (Wyrtki, 1964), so that a knowledge of temperature distribution, in itself, would not show us where skipjack are concentrated. However, consideration of temperature information in conjunction with the distribution of skipjack forage organisms might help identify areas of potential skipjack abundance.

Alverson (1963) and Waldron and King (1963) listed the prey organisms of skipjack tuna in the eastern tropical Pacific and central Pacific, respectively. Nakamura (1965) gave similar information for skipjack of the Marquesas and Tuamotu Islands, between about long 135 and 155 W in the south Pacific. Most of the skipjack stomachs that Alverson (1963) studied were collected within about 500 miles of the tropical American Pacific coast. The stomachs studied by Waldron and King (1963) were collected broadly between long 150 and 180 W. The results of skipjack stomach content studies are summarized in Table 1. Alverson (1963) and Nakamura (1965) noted a tendency for skipjack over 60 cm long to have a smaller proportion of crus-

Table 1. Summary of results of stomach content analyses of skipjack tuna.

References	Number of stomachs	Percentage composition			Percentage frequency		
		Crustaceans	Fishes	Cephalopods	Crustaceans	Fishes	Cephalopods
Alverson (1963)	2317	59	3	37	76	36	13
Waldron and King (1963)	707	4	75	20	41	76	40
Nakamura (1965)	603	-	-	-	72	77	24

taceans in the diet than smaller skipjack in some areas, but Waldron and King (1963) found no significant difference in the representation of total crustaceans, fishes, or cephalopods in skipjack under and over 60 cm.

The prey of skipjack tuna form part of the assemblage of active pelagic fishes, cephalopods, and crustaceans about 1 to 10 cm in size, which we call micronekton. Micronekton collections were taken during EASTROPAC cruises, and the organisms known or expected to be prey of skipjack, based on the above-cited food habit studies, were sorted out and measured volumetrically. This report describes the distribution of the total of these skipjack-forage organisms as a contribution to skipjack ecology. Other aspects of the study of EASTROPAC micronekton samples, including organisms that are not eaten by skipjack, are described elsewhere (Blackburn et al., 1970).

MATERIAL AND METHODS

Seasonally repetitive oceanographic observations were made in the eastern tropical Pacific between lat 20° N and 20° S, bounded in the east by the American coast and in the west usually by long 119° W. During EASTROPAC, seven cruises were made of approximately 2 months each: February-March 1967, April-May 1967, June-July 1967, August-September 1967, October-November 1967, December 1967-January 1968, and February-March 1968. Figures 1(A, B) through 7(A, B) show the extent of the coverage in the eastern tropical Pacific during the successive periods. Most of the data were collected west and south of the existing skipjack fishing areas near the American coast.

We sampled micronekton on these cruises in oblique hauls of a large net, 1.5 m square at the mouth, with a uniform mesh size that retains animals $\geq$ 1 cm but not smaller (Blackburn, 1968; Jerde, 1967). The micronekton samples were taken from the surface to a depth of approximately 200 m, with ship speeds during the hauls ranging from 4.0 to 6.4 knots. The volumes of water strained were estimated as described by Blackburn et al. (1970). The displacement volume of the total skipjack forage was measured and standardized in ml/1000 m^3 of water strained for each haul. Generally, two micronekton hauls were made during each 24-hr period, one usually close to local apparent noon and the other usually close to local midnight. The day-time catches were usually about one-tenth the size of the night catches, by volume. Similar day-night differences have been observed in other micronekton studies and have been shown to be due to net avoidance and vertical migration of organisms (Pearcy and Laurs, 1966). Because of their larger size, the night samples may give a better representation of the total amounts of skipjack forage present. However, it was considered important to sample in the daytime also because skipjack probably do much of their feeding during hours of daylight (Nakamura, 1962). In addition, two hauls per diel period were expected to give better resolution of the positions of maxima and minima of forage, than one haul. An estimate of sampling variability for night catches is given by a series of 11 catches made during one night at approximately the same geographical position. The coefficient of variation of the total micronekton volume was 20%.

The following components of the micronekton net catches are regarded collectively as skipjack forage: *Vinciguerria* spp., all epipelagic fishes, *Pleuroncodes* spp., all other crustaceans, and all cephalopods. The following other components were not considered part of skipjack forage: leptocephali, all mesopelagic fish except *Vinciguerria*, and large watery plankters such as salps and medusae. Fishes with photophores were called mesopelagic, most others epipelagic. Leptocephali are transparent and would probably be hard for skipjack to see, and there is no evidence that skipjack eat them. Mesopelagic fishes mostly occur near the surface at night, and with the very important exception of *Vinciguerria*, they are seldom an important item in skipjack stomach contents in the eastern or central tropical Pacific (Alverson, 1963; Waldron and King, 1963; Nakamura, 1965). The epipelagic fishes, crustaceans, and cephalopods have not yet been completely sorted to families. They may therefore have included some families which Alverson, Waldron and King, and Nakamura did not find in skipjack stomachs. However, we have no reason to think that any member of these families would not be eaten since tunas are opportunistic feeders within their sensory and behavioral limitations (Blackburn, 1968).

Catches of micronekton by large nets and small midwater trawls give imperfect estimates of the availability of tuna forage (King and Iversen, 1962; Laurs and Nishimoto[1]). Highly mobile epipelagic fishes and cephalopods may avoid the net. Some small components of the forage, such as euphausiids, may pass through the meshes of some nets, although not the net used in this study. Nevertheless, our measurements of standardized displacement volume of potential skipjack forage no doubt validly distinguish areas where forage is rich and poor and are the best relative estimates of potential skipjack forage that can be produced at this time.

RESULTS

Figures 1(A)-7(A) and 1(B)-7(B) show the distribution of potential skipjack forage as indicated by night and day micronekton samples, respectively, collected on the seven EASTROPAC cruises. Contours represent concentrations of the forage organisms as indicated by the collections; the night values are greater than the day values on similar contours by a factor of 10, e.g., 80 ml/1000 m^3 (night) and 8.0 ml/1000 m^3 (day). Heavy dashed lines in the figures indicate positions of zonally (latitudinally) oriented maxima. Where the position of such a line is not clearly justified by the contours, it is based on differences in actual concentration within the same contour interval.

It is convenient to mention first the features of forage distribution for the area west of long 92° W. Most of this part of the EASTROPAC area is not presently fished for skipjack, and the positions of forage maxima may indicate where skipjack are most abundant. The area east of long 92° W is discussed secondly.

[1]Laurs, R. M., and R. N. Nishimoto. Food of troll-caught Pacific albacore, *Thunnus alalunga* (Bonnaterre), and an evaluation of midwater trawl catches as a measure of potential albacore food. National Marine Fisheries Service, Fishery-Oceanographic Center, La Jolla, Calif. 92037. Manuscript.

Area West of Long 92° W

The most conspicuous maximum occurs in a zonal band between lat 0° and 5° N. It is evident on at least two adjacent sampled meridians in each figure except 6(B). It appears to be well developed for both night and day forage at all seasons. Another maximum sometimes occurs between lat 2° and 8° S. Figures 1(A), 1(B), 4(B), and 6(A) show it on at least two adjacent meridians. It generally has lower concentrations over a smaller area and is less continuous zonally than the maximum just north of the equator. The data do not justify any statement about seasonal changes in its development. A zonal maximum also occurs with some regularity between 6° and 14° N. It is evident on two or more adjacent meridians in each figure except 4(A), 5(A), and 6(B). This maximum is generally more evident in the charts of the distribution of day forage than in the charts of night forage. There appears to be no great seasonal change in its development, and forage concentrations are generally lower than in the northern equatorial maximum.

High concentrations of forage appear in several of the charts in the northwestern part of the area, approximately north of lat 14° N and west of long 107° W [Figs. 1(A), 2 (B), 4(A), 4(B), 5(B), and 7(A)]. For some cruises they are more conspicuous in the night forage than in the day forage; for others, the reverse. Other maxima appear irregularly in generally smaller areas. Forage concentrations in the southern part of the area, and in the northwestern part with the exceptions mentioned above, tend to be low.

Area East of Long 92° W

In the area east of long 92°W, which was sampled less frequently than the more offshore area, the main maxima are coastal. They vary in position, however, not only between cruises but also between night and day forage distributions for the same cruise. High values are usually observed off Peru and/or Ecuador, and moderate values sometimes occur in the region of the Panama Bight. Except near Peru, the maximum concentrations near the coast are no

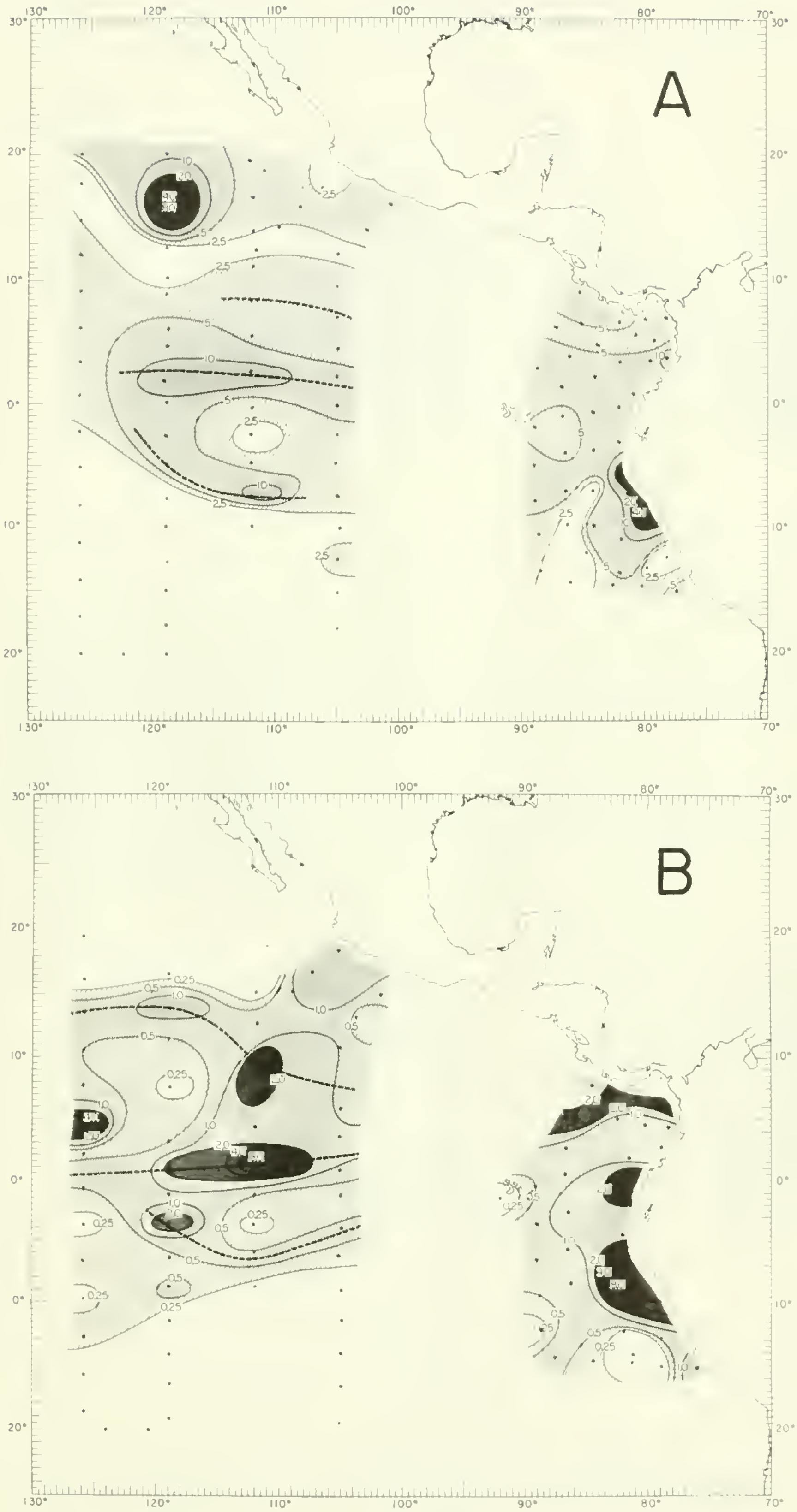

Figure 1.—Concentrations of skipjack forage measured in the first cruise period of the EASTROPAC expedition, February-March 1967, in ml/1000 m^3: (A) at night stations; (B) at day stations. Heavy dashed lines indicate positions of zonally oriented maxima.

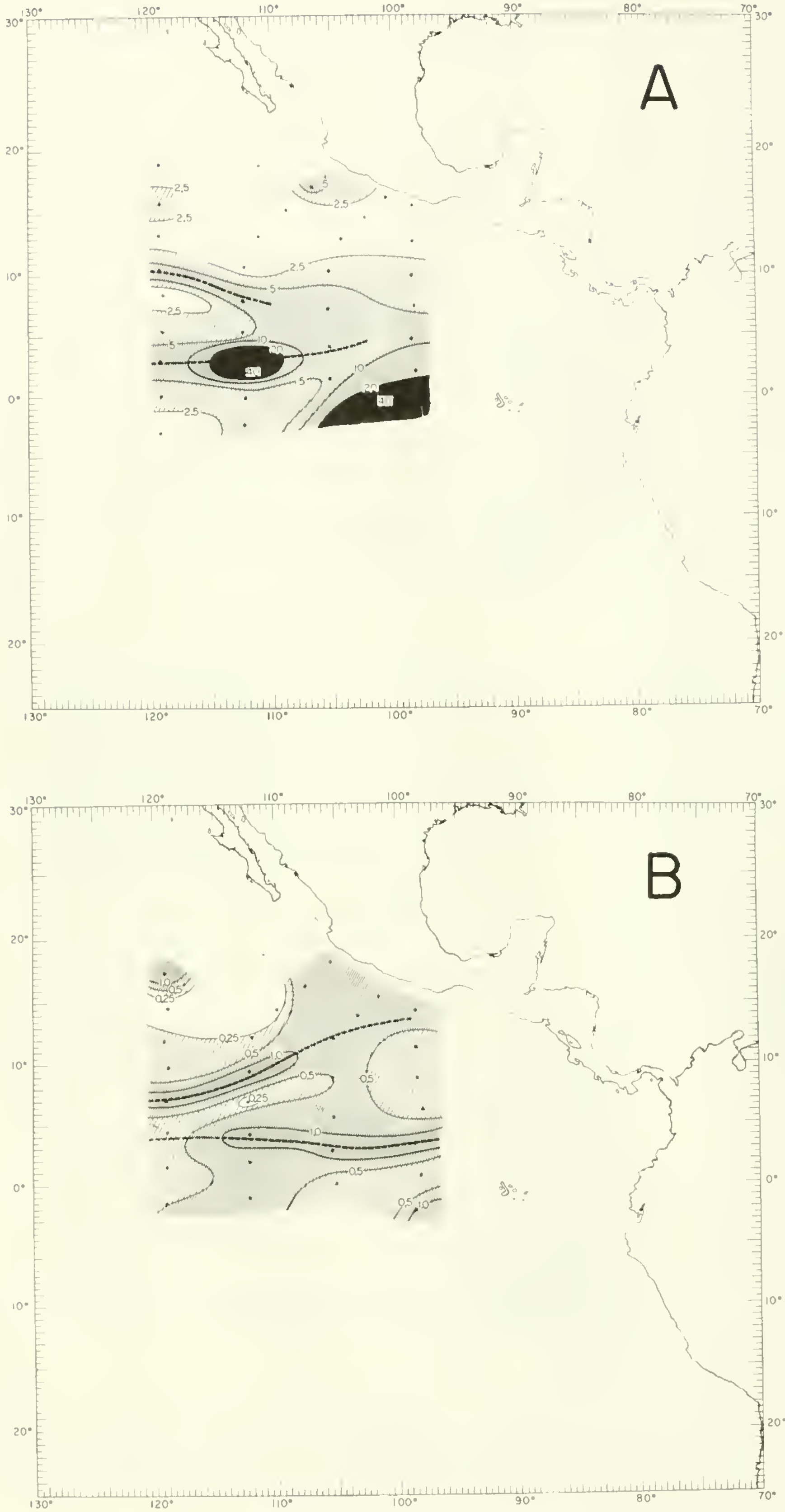

Figure 2.—Concentrations of skipjack forage measured in the second cruise period of the EASTROPAC expedition, April-May 1967, in ml/1000 m³: (A) at night stations; (B) at day stations. Heavy dashed lines indicate positions of zonally oriented maxima.

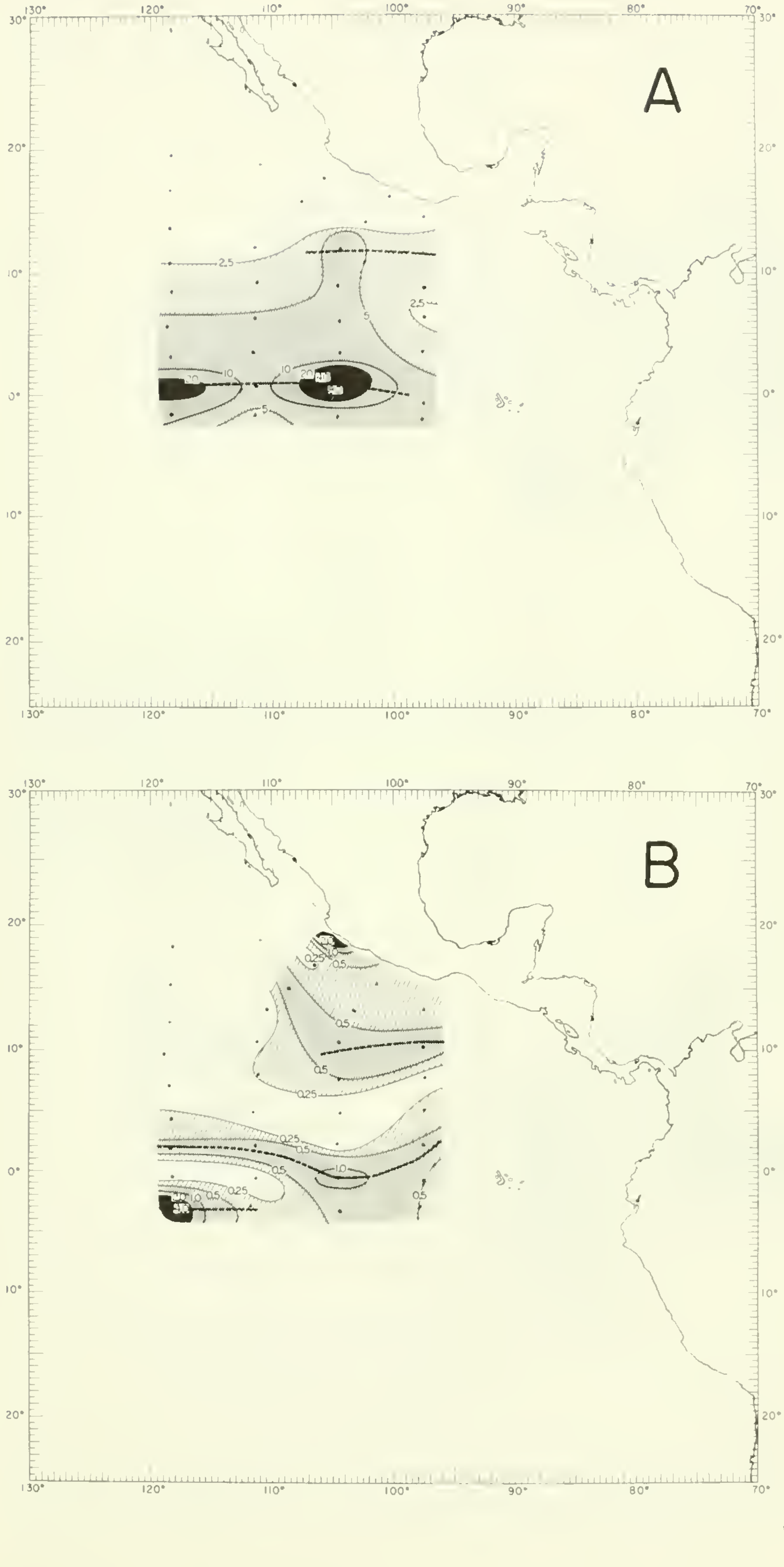

Figure 3.—Concentrations of skipjack forage measured in the third cruise period of the EASTROPAC expedition, June-July 1967, in ml/1000 m³: (A) at night stations; (B) at day stations. Heavy dashed lines indicate positions of zonally oriented maxima.

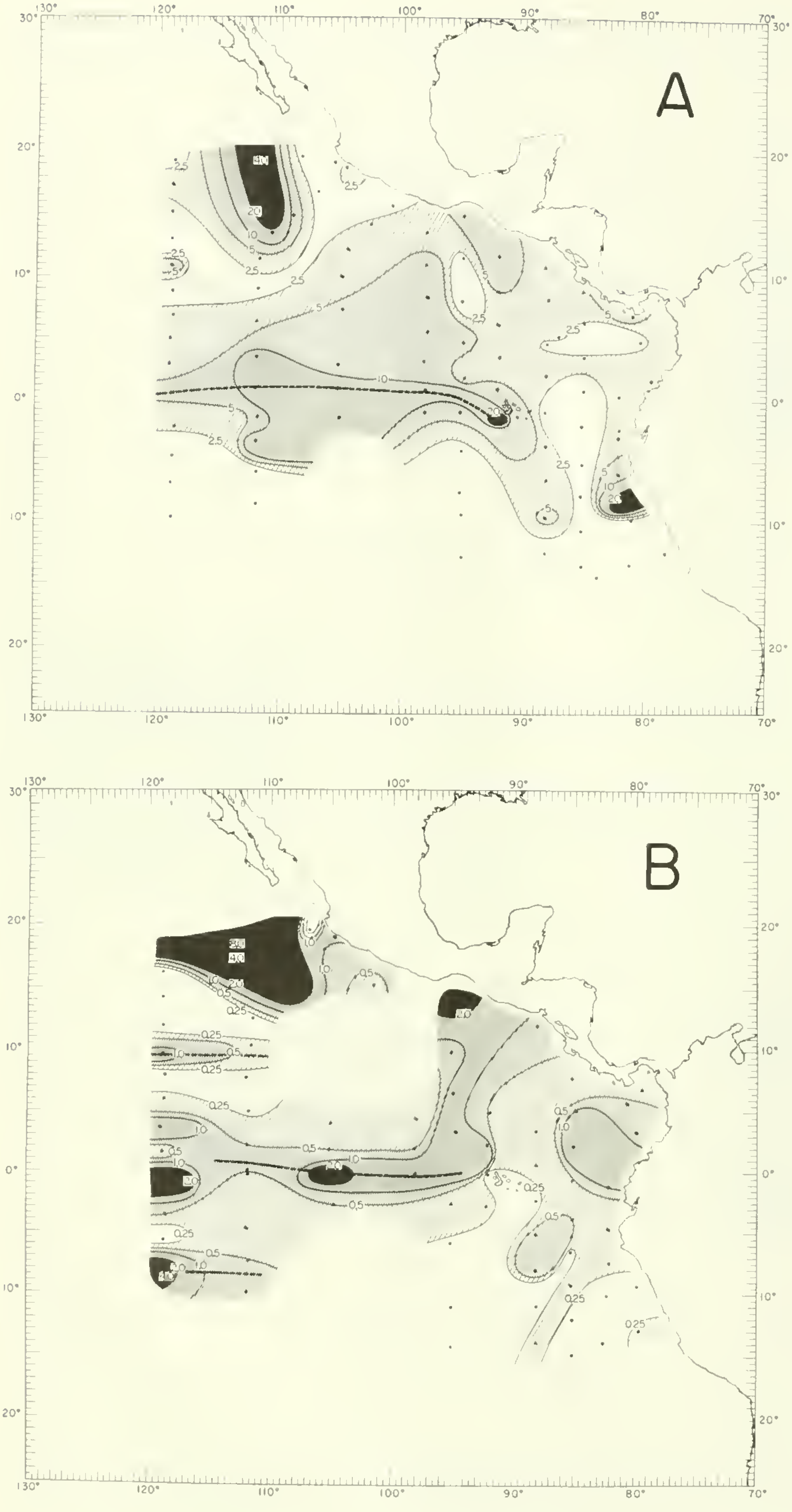

Figure 4.—Concentrations of skipjack forage measured in the fourth cruise period of the EASTROPAC expedition, August-September 1967, in ml/1000 m^3: (A) at night stations; (B) at day stations. Heavy dashed lines indicate positions of zonally oriented maxima.

Figure 5.—Concentrations of skipjack forage measured in the fifth cruise period of the EASTROPAC expedition, October-November 1967, in ml/1000 m^3: (A) at night stations; (B) at day stations. Heavy dashed lines indicate positions of zonally oriented maxima.

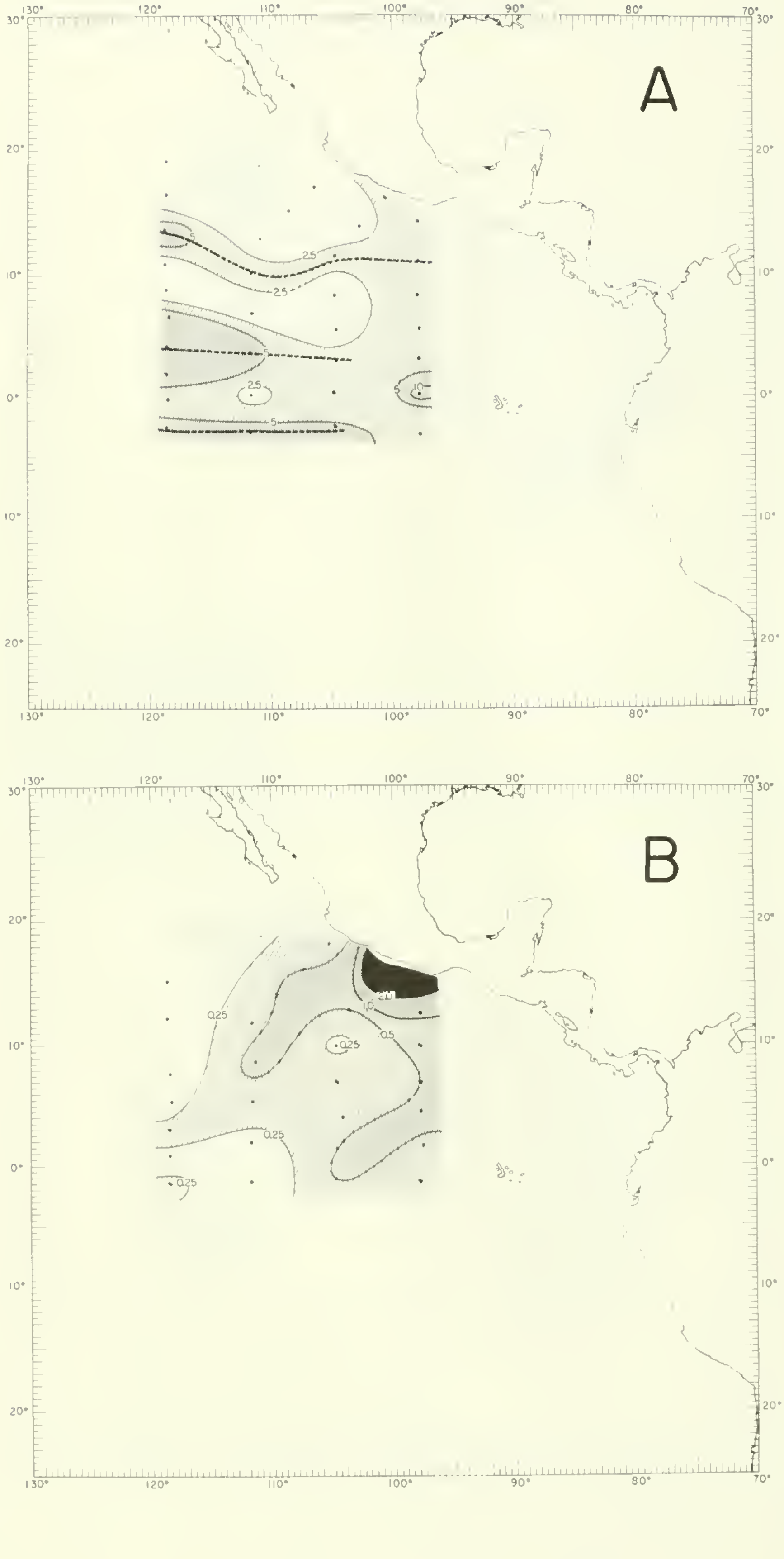

Figure 6.—Concentrations of skipjack forage measured in the sixth cruise period of the EASTROPAC expedition, December 1967-January 1968, in ml/1000 m^3: (A) at night stations; (B) at day stations. Heavy dashed lines indicate positions of zonally oriented maxima.

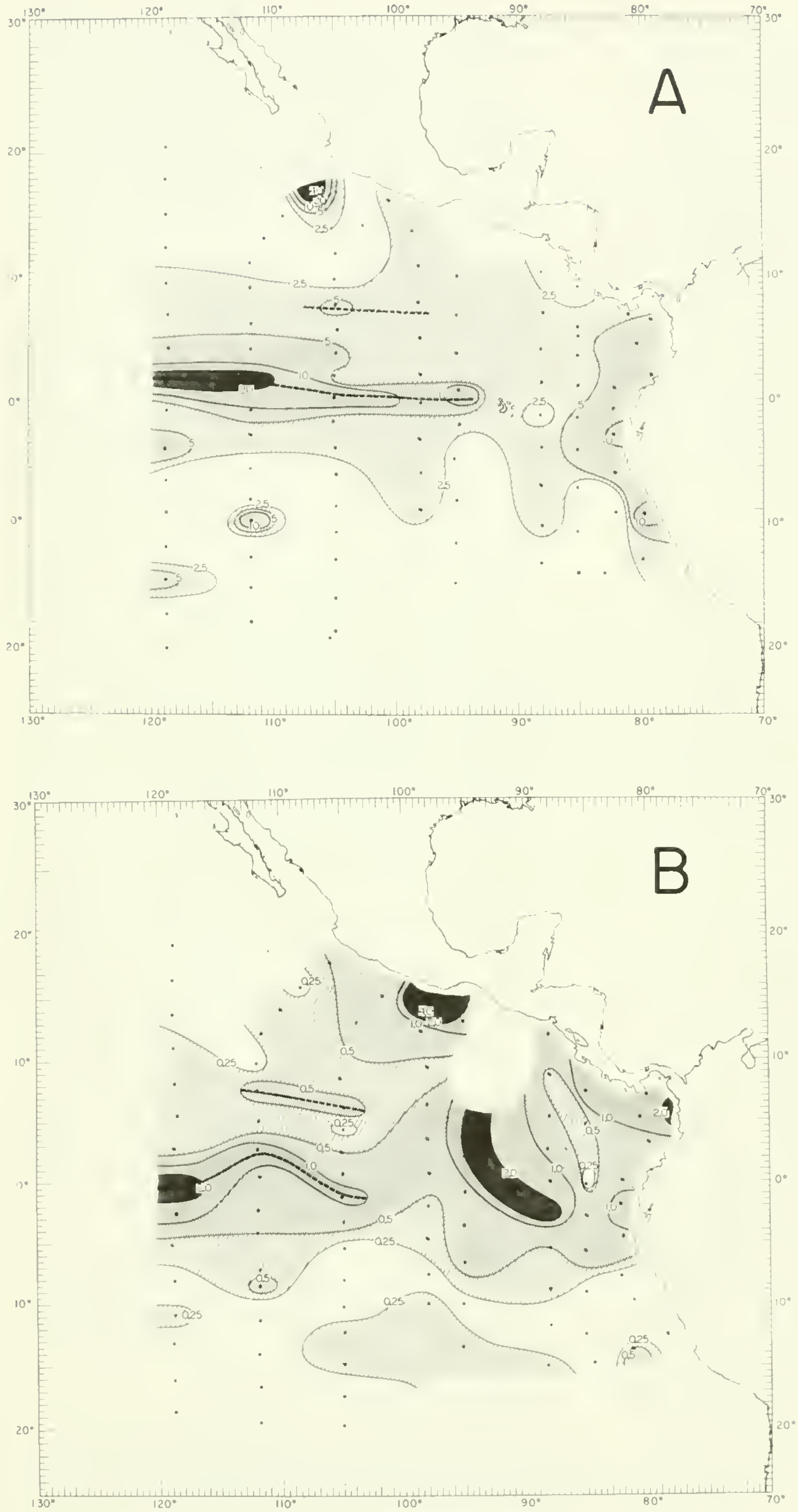

Figure 7.—Concentrations of skipjack forage measured in the seventh cruise period of the EASTROPAC expedition, February-March 1968, in ml 1000 m^3 : (A) at night stations; (B) at day stations. Heavy dashed lines indicate positions of zonally oriented maxima.

higher and sometimes lower than maximum concentrations west of long 92° W.

A variable area of low forage, centered at about lat 1° S between long 85° and 92° W, is recognizable in Figures 1(A), 1(B), 4(A), 4(B), 5(A), 7(A), and 7(B). It may extend farther north, as in Figure 7(B), or south, as in Figure 4(A). Another minimum, oriented more or less zonally, appears in Figures 1(A), 1(B), 4(A), and 7(B). It occurs between lat 0° and 7° N, long 90° W, and the coast.

Tables 2 and 3 show the percentage volumetric composition of night and day skipjack forage, respectively, in the regions of the abovementioned maxima, in terms of the five categories of organisms for which data are available. The most striking difference is between the forage in the maximum in the northwestern part of the area, which consists predominantly of the pelagic galatheid crustacean *Pleuroncodes planipes*, and that in the other maxima, where other crustaceans predominate. The taxonomic groups of forage animals in the maximum at lat 6°-14° N are more equal in quantity than elsewhere, both by night and day.

DISCUSSION

Skipjack fisheries presently exist in many of the areas where high concentrations of forage were observed on the EASTROPAC cruises. These include 1) along the American coast, 2) in the Galápagos Islands region, centered at about long 91° W and the equator, and 3) in

Table 2. Percentage volumetric composition of night skipjack forage in the areas of the principal maxima in the EASTROPAC region.

Maxima	Components of skipjack forage					
	Vinciguerria	Epipelagic fish	Pleuroncodes	Other crustaceans	Cephalopods	Total
West of 92° W						
2° to 8° S	2.1	3.0	-	69.4	25.5	100.0
0° to 5° N	1.1	0.3	-	95.3	3.3	100.0
6° to 14° N	3.6	11.5	9.0	61.4	14.5	100.0
North of 14° N, west of 107° W	2.2	1.8	94.6	1.1	0.3	100.0
East of 92° W						
South American coast	1.1	4.2	-	91.5	3.2	100.0

Table 3. Percentage volumetric composition of day skipjack forage in the areas of the principal maxima in the EASTROPAC region.

Maxima	Components of skipjack forage					
	Vinciguerria	Epipelagic fish	Pleuroncodes	Other crustaceans	Cephalopods	Total
West of 92° W						
2° to 8° S	-	0.9	-	93.8	5.3	100.0
0° to 5° N	0.3	0.3	-	87.0	12.4	100.0
6° to 14° N	1.9	0.6	0.6	81.9	15.0	100.0
North of 14° N, west of 107° W	1.0	-	96.0	2.8	0.2	100.0
East of 92° W						
South American coast	-	1.2	-	96.9	1.9	100.0

the Revillagigedo Islands region, between lat 18 and 20 N in the northwestern part of the EASTROPAC area (Joseph and Calkins, 1969; Williams, 1970). We are here concerned with the possibilities of occurrence of abundant skipjack in other, more offshore areas where high concentrations of potential skipjack forage regularly occur and where little or no fishing has been done. These are located west of long 95 W just north and south of the equator, and between lat 6 and 14 N; and in the northwestern part of the area between about lat 14 and 18 N. Since the levels of forage concentration in these unexploited areas are comparable with the maximum levels in the areas that are exploited, they may be equally attractive to skipjack.

There is a broad basis for the expected association of abundant adult skipjack with the high offshore forage concentrations. Skipjack are fairly heavy feeders, eating the equivalent of 15% of their body weight per feeding day of 12 daylight hours when fed to satiation (Magnuson, 1969); therefore, they would be expected to aggregate in productive areas of abundant forage. Also, skipjack are known to be highly mobile animals with maximum swimming speeds in excess of 10 body lengths/sec (Blaxter, 1969) and cruising speeds up to 6 body lengths/sec (Yuen, 1970), clearly able to leave areas in which the forage is sparse in search of richer areas elsewhere. When skipjack migrate between the central and eastern Pacific, they possibly remain in biologically productive latitudes (Williams[5]).

The above-mentioned areas of offshore forage maxima would not be expected to contain skipjack, in commercial concentrations, if surface temperatures were unsuitable, i.e., under 20 or over 29 C. Sea-surface-temperature information for the eastern tropical Pacific (Wyrtki, 1964; La Violette and Seim, 1969; monthly charts issued by the National Marine Fisheries Service, La Jolla, California) indicates that the forage maximum in unfished areas lying just north of the equator might occasionally be too cold for skipjack at some longitudes west of the Galápagos Islands in the months July through November, although longitudes west of 117 W would probably not be affected. The same might apply to the maximum south of the equator. The maximum at lat 6 -14 N might occasionally be too warm for skipjack in some or all of the areas where we have found it, especially in the months of July through October. If fisheries develop in the areas of these forage maxima, monitoring or forecasting the occurrences of unusually high or low surface temperatures might be useful to fishermen.

The zonal maximum just north of the equator has been observed before, both in the EASTROPAC area and farther west in the central Pacific, by King (1958) and King and Iversen (1962). These authors also observed a second zonal maximum just south of the equator (lat 2 S) on one occasion at long 120 W (but not at 112), although they did not comment upon it. King (1958) suggested an explanation of the northern maximum based on the work of Cromwell (1953). Northerly and southerly components of water transport result from the equatorial divergence, and because the prevailing winds are from the southeast, the major drift of newly upwelled water is towards the north. As this drifting water becomes older it gets warmer, and this together with its nutrient richness enables it to support large populations of organisms. The organisms at successively higher trophic levels reach their biomass maxima at successively longer intervals of time, and thus of space, from the original upwelling; therefore, the forage maximum will occur some distance north of the center of the equatorial upwelling. We would amend this interpretation to include the situation where the drift of the upwelled water is to the south, whereby a forage maximum may occur south of the equator, although less pronounced than the northern one, as we have observed in this paper. Similar ideas have been expressed by Vinogradov and Voronina (1965).

The zonal maximum of skipjack forage between lat 6 and 14 N may represent a result of high biological production along the ridge in the strong thermocline that occurs in those lati-

[5]Williams, F. Meteorology, oceanography, and migrations of recruit skipjack in the eastern Pacific Ocean. Scripps Tuna Oceanography Research Program, Institute of Marine Resources, Scripps Institution of Oceanography, La Jolla, Calif. 92037. Manuscript.

tudes along the northern edge of the North Equatorial Countercurrent (Wyrtki, 1964, 1965). We have observed elsewhere (Blackburn et al., 1970) that night micronekton does not show a clear maximum in these latitudes, although such a maximum might be expected, and zooplankton shows one. The data in this paper show a moderate maximum of skipjack forage, especially in day samples, although we do not know why day samples should give a different picture. Possibly the distribution of organisms is more even within the sampled water column by day than by night. If the organisms that occur at night were restricted to a thin layer of water (e.g., above the thermocline) and occurred there in patches, oblique hauls would sometimes under-sample them.

The forage maxima in the northwestern part of the EASTROPAC area occur in an area of relatively thick mixed layer (Wyrtki, 1964) and low biological production (Blackburn, 1966). They represent occurrences of red crabs, *Pleuroncodes planipes*, that may have been transported from the upwelling off the coast of Baja California by the California Current (Longhurst, 1967; Longhurst and Seibert, 1971).

Regarding the relations of forage maxima and minima to physical features and processes in waters between 92° W and the coast, we refer the reader to our observations published elsewhere on maxima and minima of EASTROPAC micronekton (Blackburn, et al., 1970).

Three successful attempts have been made to demonstrate the abundance of skipjack in the EASTROPAC area since results described in this paper were first announced. Hida (1970) made a meridional crossing of the equator at about long 119° W in October 1969 between lat 6° S and 5° N. Skipjack were caught by trolling or live-bait fishing along most parts of the track, especially at three locations from lat 2° to 5° N where over 100 fish (including large ones) were caught with little effort at each location. Trolling also gave very promising results between lat 6° and 9° N at long 122°-125° W. A few fish were taken by live-bait fishing at about lat 4° S on long 119° W. Thus, skipjack were reasonably abundant at lat between 4° S and 9° N, a range which normally includes the northern equatorial forage maximum, part of the southern equatorial maximum, and part of the zonal maximum that occurs between lat 6° and 14° N. Williams (1971) reported on skipjack caught by trolling at various latitudes broadly along long 119° W in November and December 1970. The skipjack were most abundant in the region of the northern equatorial forage maximum, specifically at lat 1°-5° N. One of us (M. Blackburn) led a similar cruise broadly along long 119° W, in March and April 1971. On that occasion the abundance of trolled skipjack was highest at lat 9°-11° N, and next highest at lat 1°-3° N; skipjack forage was more abundant in both those zones than elsewhere. Further information about the cruises in 1970 and 1971 will be published later.

LITERATURE CITED

ALVERSON, F. G.

1963. The food of yellowfin and skipjack tunas in the eastern tropical Pacific Ocean. Inter-Am. Trop. Tuna Comm., Bull. 7: 293-396. [English and Spanish.]

BLACKBURN, M.

1965. Oceanography and the ecology of tunas. Oceanogr. Mar. Biol. Annu. Rev. 3: 299-322.

1966. Biological oceanography of the eastern tropical Pacific: summary of existing information. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 540, 18 p.

1968. Micronekton of the eastern tropical Pacific Ocean: family composition, distribution, abundance, and relations to tuna. U.S. Fish Wildl. Serv., Fish. Bull. 67: 71-115.

1969. Conditions related to upwelling which determine distribution of tropical tunas off western Baja California. U.S. Fish Wildl. Serv., Fish. Bull. 68: 147-176.

BLACKBURN, M., R. M. LAURS, R. W. OWEN, and B. ZEITZSCHEL.

1970. Seasonal and areal changes in standing stocks of phytoplankton, zooplankton, and micronekton in the eastern tropical Pacific. Mar. Biol. 7: 14-31.

BLAXTER, J. H. S.
1969. Swimming speeds of fish. FAO Fish. Rep. 62: 69-100.

CROMWELL, T.
1953. Circulation in a meridional plane in the central equatorial Pacific. J. Mar. Res. 12: 196-213.

HIDA, T. S.
1970. Surface tuna schools located & fished in equatorial eastern Pacific. Commer. Fish. Rev. 32(4): 34-37.

INTER-AMERICAN TROPICAL TUNA COMMISSION.
1970. Annual report of the Inter-American Tropical Tuna Commission, 1969, 117 p. [English and Spanish.]

JERDE, C W.
1967. A comparison of euphausiid shrimp collections made with a micronekton net and a one-meter plankton net. Pac. Sci. 21: 178-181.

JOSEPH, J., and T.P. CALKINS.
1969. Population dynamics of the skipjack tuna (*Katsuwonus pelamis*) of the eastern Pacific Ocean. Inter-Am. Trop. Tuna Comm., Bull. 13: 1-273. [English and Spanish.]

KING, J. E.
1958. Variation in abundance of zooplankton and forage organisms in the central Pacific in respect to the equatorial upwelling. Proc. Ninth Pac. Sci. Congr. 16: 98-107.

KING, J. E., and R. T. B. IVERSEN.
1962. Midwater trawling for forage organisms in the central Pacific 1951-1956. U.S. Fish Wildl. Serv., Fish. Bull. 62: 271-321.

LA VIOLETTE, P. E., and S. E. SEIM.
1969. Monthly charts of mean, minimum, and maximum sea surface temperature in the North Pacific Ocean. U.S. Nav. Oceanogr. Off. Spec. Publ. SP-123, 62 p.

LONGHURST, A. R.
1967. The pelagic phase of *Pleuroncodes planipes* Stimpson (Crustacea, Galatheidae) in the California Current. Calif. Coop. Oceanic Fish. Invest. Rep. 11: 142-154.

LONGHURST, A. R., and D. L. R. SEIBERT.
1971. Breeding in an oceanic population of *Pleuroncodes planipes* (Crustacea, Galatheidae). Pac. Sci. 25: 426-428.

MAGNUSON, J. J.
1969. Digestion and food consumption of skipjack tuna (*Katsuwonus pelamis*). Trans. Am. Fish. Soc. 98: 379-392.

MIYAKE, M. P.
1968. Distribution of skipjack in the Pacific Ocean, based on records of incidental catches by the Japaneese longline tuna fishery. Inter-Am. Trop. Tuna Comm., Bull. 12: 511-608 [English and Spanish.]

NAKAMURA, E. L.
1962. Observations on the behavior of skipjack tuna, *Euthynnus pelamis*, in captivity. Copeia 1962: 499-505.

1965. Food and feeding habits of skipjack tuna (*Katsuwonus pelamis*) from the Marquesas and Tuamotu Islands. Trans. Am. Fish. Soc. 94: 236-242.

PEARCY, W. G., and R. M. LAURS.
1966. Vertical migration and distribution of mesopelagic fishes off Oregon. Deep-Sea Res. 13: 153-165.

ROTHSCHILD, B. J.
1965. Hypotheses on the origin of exploited skipjack tuna (*Katsuwonus pelamis*) in the eastern and central Pacific Ocean. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 512, 20 p.

VINOGRADOV, M. E. and N. M. VORONINA.
1965. Some peculiarities of plankton distribution in the Pacific and Indian equatorial current areas. (In Russian; English abstract.) Okeanolog. Issled., Rez. Issled. po Programme Mezhd. Geofiz. Goda, Mezhd. Geofiz. Komitet, Prezidiume Akad. Nauk. USSR. 13: 128-136. [English abstract in Deep-Sea Res. 13: 146 (1966) was seen.]

WALDRON, K. D., and J. E. KING.
1963. Food of skipjack in the central Pacific. *In* H. Rosa, Jr. (editor), Proceedings of the world scientific meeting on the biology of tunas and related species, p. 1431-1457, FAO Fish. Rep. 6.

WILLIAMS, F.
1970. Sea surface temperature and the distribution and apparent abundance of skipjack (*Katsuwonus pelamis*) in the eastern Pacific Ocean, 1951-1968. Inter-Am. Trop. Tuna Comm., Bull. 15: 229-281. [English and Spanish.]

1971. Current skipjack oceanography cruises in eastern tropical Pacific Ocean. Commer. Fish. Rev. 33(2): 29-38.

WYRTKI, K.
1964. The thermal structure of the eastern Pacific Ocean. Dtsch. Hydrogr. Z., Ergänzungsheft reihe A, 6, 84 p.

1965. Surface currents of the eastern tropical Pacific Ocean. Inter-Am. Trop. Tuna Comm., Bull. 9: 271-304. [English and Spanish.]

YUEN, H. S. H.
1970. Behavior of skipjack tuna, *Katsuwonus pelamis*, as determined by tracking with ultrasonic devices. J. Fish. Res. Board Can. 27: 2071-2079.

salmon (models I and II), by Daniel W. Bates and John G. Vanderwalker, pp. 1-5, 6 figs., 1 table; 2d paper, Design and operation of a cantilevered traveling fish screen (model V), by Daniel W. Bates, Ernest W. Murphey, and Earl F. Prentice, 10 figs., 1 table.

609. Annotated bibliography of zooplankton sampling devices. By Jack W. Jossi. July 1970, iii + 90 pp.

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615. Distribution of fishing effort and catches of skipjack tuna, *Katsuwonus pelamis*, in Hawaiian waters, by quarters of the year, 1948-65. By Richard N. Uchida. June 1970, iv + 37 pp., 6 figs., 22 tables.

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620. The Trade Wind Zone Oceanography Pilot Study. Part IX: The sea-level wind field and wind stress values, July 1963 to June 1965. By Gunter R. Seckel. June 1970, iii + 66 pp., 5 figs.

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622. Number and lengths, by season, of fishes caught with an otter trawl near Woods Hole, Massachusetts, September 1961 to December 1962. By F. E. Lux and F. E. Nichy. February 1971, iii + 15 pp., 3 figs., 19 tables.

623. Apparent abundance, distribution, and migrations of albacore, *Thunnus alalunga*, on the North Pacific longline grounds. By Brian J. Rothschild and Marian Y. Y. Yong. September 1970, v + 37 pp., 19 figs., 5 tables.

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626. Commercial fishery and biology of the freshwater shrimp, *Macrobrachium*, in the Lower St. Paul River, Liberia, 1952-53. By George C. Miller. February 1971, iii + 13 pp., 8 figs., 7 tables.

629. Analysis of the operations of seven Hawaiian skipjack tuna fishing vessels, June-August 1967. By Richard N. Uchida and Ray F. Sumida. March 1971, v + 25 pp., 14 figs., 21 tables. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 - 35 cents.

633. Blueing of processed crab meat. II. Identification of some factors involved in the blue discoloration of canned crab meat (*Callinectes sapidus*). By Melvin E. Waters. May 1971, iii + 7 pp., 1 fig., 3 tables.

636. Oil pollution on Wake Island from the tanker *R. C. Stoner*. By Reginald M. Gooding. May 1971, iii + 12 pp., 8 figs., 2 tables. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 - Price 25 cents.

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